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Review

What do we know about the healthcare costs of extreme heat exposure? A comprehensive literature review

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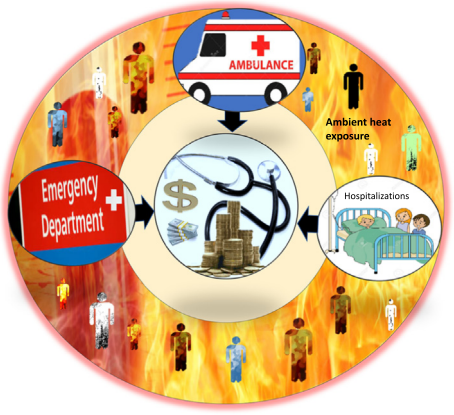
HIGHLIGHTS

- Heat exposure was causing a substantial economic burden on healthcare systems.
- Heat attributable healthcare costs are likely to increase in a changing climate.
- Females, the elderly, and low income groups had the highest heat healthcare costs.
- More evidence is needed for the evaluation of heat attributable healthcare costs.

GRAPHICAL ABSTRACT



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ABSTRACT

Exposure to extreme heat can lead to a range of heat-related illnesses, exacerbate pre-existing health conditions and cause increased demand on the healthcare system. A projected increase in temperature may lead to greater healthcare expenditure, however, at present the costs of heat-related healthcare utilization is under-researched. This study aims to review the literature on heat-related costs for the healthcare system with a focus on ED visits, hospitalization, and ambulance call-outs. PubMed, Scopus, and Embase were used to search relevant literature from database inception to December 2017 and limited to human studies and English language. After screening, a total of ten papers were identified for final inclusion. In general, the healthcare costs of heat extremes have been poorly investigated in developed countries and not reported in developing countries where the largest heat-vulnerable populations reside. Studies showed that exposure to extreme heat was causing a substantial economic burden on healthcare systems. Females, the elderly, low-income families, and ethnic minorities had the highest healthcare costs on a range of health services utilization. Although a few studies have estimated heat healthcare costs, none of them quantified the temperature-healthcare cost relationship. There is a need to systematically examine heat-attributable costs for the healthcare system in the context of climate change to better inform heat-related policy making, target interventions and resource allocation.

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1. Introduction

The global burden of disease treatment is a growing economic cost (Yach et al., 2004; Bell et al., 2014). Decision makers at all levels of the healthcare system are increasingly facing the challenges of reconciling the ever increasing demand for healthcare services with limited resources (Palmer and Torgerson, 1999; Goeree and Diaby, 2013). While many health promotion and disease prevention measures can improve health outcomes at relatively low cost, only a small fraction of health spending goes on prevention activities (Gmeinder et al., 2017). Environmental factors are among the major determinants of health, and can include such factors as climate and weather (Smith et al., 1999). Interventions to mitigate the effects of these factors could provide sustainable health benefits with low opportunity costs. However, the health costs associated with climatic factors, and the potential health and economic benefits of relevant interventions have not been explored (Severens and Milne, 2004).

At present, extreme heat has been identified as a major environmental hazard for population health (Houghton et al., 2017). Many epidemiological studies have shown that extreme heat is associated with excess morbidity and mortality, resulting in increased ambulance call-outs (Ordon et al., 2016; Turner et al., 2013; Nitschke et al., 2011; Zuo et al., 2015), emergency department (ED) visits (Zuo et al., 2015; Chen et al., 2017; Fuhrmann et al., 2016; Ghirardi et al., 2015; Zheng et al., 2016), and hospitalizations (Zuo et al., 2015; Phung et al., 2017; Isaksen et al., 2015; Liss et al., 2017; Williams et al., 2012). Nonetheless, costs associated with heat driven healthcare service utilization is under researched. The predicted increase in the frequency, intensity, and duration of hot days under climate change scenarios are likely to cause more adverse health outcomes (Pachauri et al., 2014), which may subsequently burden the already overloaded and budget-constrained healthcare system (Saniotis and Bi, 2009; Schieppati and Remuzzi, 2005), especially for some middle- and low-income countries.

Heat-related health effects have economic consequences through incurred medical treatment and healthcare costs, and loss of work productivity (Schmitt et al., 2016). Heat attributable sicknesses and complications may demand advanced medical technologies, services, and extended hospitalizations which may lead to huge medical expenses. Heat driven health cost can be described as direct (health interventions) and indirect (productivity) costs (Fig. 2). The direct costs can be further classified into healthcare cost (cost to the healthcare provider) and non-healthcare costs (costs to patients and their family). The cost to the healthcare providers is associated with their staffs, trainings, medical devices, pharmaceuticals, diagnostic procedures (e.g. laboratory tests etc.), procedures (e.g. surgical interventions), outpatient services (GP visits, ED, etc.), inpatient services (hospital admissions), capital costs (e.g. building or space needed to deliver the intervention), overhead costs (such as light, heat or cleaning costs) and related services (community and ambulance services). The costs to patients and/or families are the narrower perspective which include costs to transport, over-the-counter drugs, and co-payments (McIntosh and Luengo-Fernandez, 2006; Nagata et al., 2018).

Indirect cost represents a significant amount of economic losses due to morbidity and mortality associated with 1) Work absenteeism which represent the lost productivity due to sick-leave and 2) Presenteeism, a reduced productivity and work performance while at work (Nagata et al., 2018). Such cost implications includes: reduced outdoor work activities, reduced economic activities, disruption to public services (including transport), losses to agricultural and horticultural enterprises, and costs to power outages (Zuo et al., 2015). Heat can also cause intangible costs (e.g. pain, anxiety) which can be measured in natural units such as quality adjusted life year (Pandit, 2016). However, this review will focuses on the direct healthcare costs of extreme heat exposure particularly to the healthcare resource utilizations such as medications, diagnosis tests, consumable medical equipment, follow-up, and ambulance services.

Heat-attributable healthcare costs represent spending for ambulance services, ED visits, and hospitalizations to save lives and restore the health of peoples affected by hot ambient temperature. Estimation of such healthcare costs due to extreme heat provides an economic perspective to the burden of heat attributable health impacts, which has been assessed mainly in terms of incidence of cases and deaths, disability-adjusted life years, and years of life lost (Huang et al., 2013; Yoon et al., 2014; Xu et al., 2014; Nitschke et al., 2007). Studies on

healthcare costs of extreme heat are currently very limited. This review aims to synthesize the published evidence on healthcare costs associated with health service usage from heat extremes. The specific research question addressed in this review is: What is the current evidence for the direct healthcare costs of extreme heat exposure, considering hospital (ED and admissions), pre-hospital (ambulance), and other primary healthcare costs? The outcomes of this review will help to inform policy-making, develop extreme heat management guidelines, and support organizational decision making on resource allocation and capacity building.

2. Methods

2.1. Search strategy

Major databases commonly used in reviews (Levi et al., 2018; Aboubakri et al., 2018) such as PubMed, Embase, and Scopus were searched to identify peer-reviewed scientific journals from a wide range of disciplines. Search term protocols included three categories of keywords: heat exposure, heat-health effects, and heat-attributable healthcare costs. Keywords and MeSH terms for heat exposure include: extreme heat, climate change, temperature, weather, hot days, heat, hot, and season; for heat-health effects, they include hospitalization, emergency, ambulance, admission, visit, triage, emergency department (ED), room, morbidity, disease, mortality, death; and for heat-attributable costs, they include costs, cost analysis, economic, health cost, hospital cost, health care cost as shown in Appendix A. The Boolean connector (Wee and Banister, 2016) "OR" was used to combine terms within each keyword and "AND" to connect each keywords to do the final literature search. Moreover, we scanned all references listed by candidate papers and searched relevant grey literature using Google Scholar.

2.2. Inclusion/exclusion criteria

Studies were selected based on the following criteria and procedures.

(1) To the authors' best knowledge, there is no previous literature review related studies around healthcare costs and extreme heat exposure, literature in English from database inception to December 2017 were included.
(2) Limited to studies of human population anywhere in the world
(3) Investigated ambulance call-out and/or, ED visit and/or, hospitalization and/or mortality in combination with ambient heat exposure and healthcare cost.
(4) Studies on cold temperature were excluded. However, literature which considered both hot and cold temperature together, only the results corresponding to the hot ambient temperature were included.
(5) Relevant literature encompassing peer-reviewed articles and grey literature were included.

The search yield was loaded into an EndNote library and selected through a four-step process, as shown in Fig. 1. First, duplicates were removed using the EndNote function of 'find duplicates'. Second, titles relevancy was reviewed. Third, the abstracts were reviewed. Finally, selected articles were fully retrieved for full-text review and evaluation. Examples of literature excluded at this stage include healthcare cost and economic evaluation based on the value of statistical life (VSL) (Ebi et al., 2004; Liao et al., 2010). Data extracted from included articles comprises first author's last name, year of publication, country, study period, heat indices, data type and sources, study design, statistical methods, main findings, and projection years (Xu et al., 2014; Li et al., 2015). For comparison purpose (Bahadori et al., 2009), all monetary costs were converted to United States Dollar (USD) based on the exchange

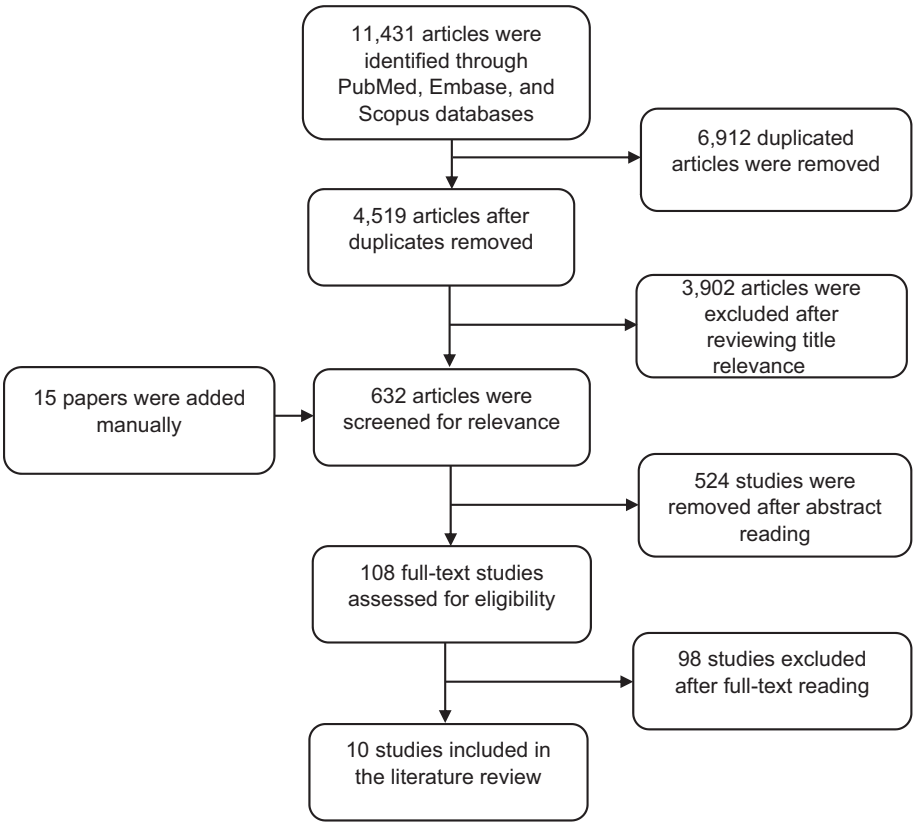
11,431 articles were identified through PubMed, Embase, and Scopus databases
6,912 duplicated articles were removed
4,519 articles after duplicates removed
3,902 articles were excluded after reviewing title relevance
15 papers were added manually
632 articles were screened for relevance
524 studies were removed after abstract reading
108 full-text studies assessed for eligibility
98 studies excluded after full-text reading
10 studies included in the literature review

Fig. 1. Selection procedures of literature for inclusion in the review.

rate on 04 May 2018 (1 USD is equivalent to 1.3266 AUD and 0.8355 Euro, respectively).

3. Results

The focus of this review is the economic costs to the health services attributable by extreme heat. The results section proceeds as follows. Under Section 3.1 we describe current evidence related to heat-related healthcare costs. In Section 3.2 we describe future heat-healthcare cost burdens of predicted climate change. In these sections, results are summarized by category of healthcare services, including pre-hospital acute care (ambulance call-outs and ED visits) and admission (inpatient) hospital services.

A total of 10 (8 peer-reviewed and 2 grey) articles were included in the final review (summarized in Table 1). All studies were from high income countries: six (60%) from the USA (Ebi et al., 2004; Jagai et al., 2017; Lin et al., 2012a; Merrill et al., 2008; Noe et al., 2012; Schmeltz et al., 2016), two from Australia (Toloo et al., 2015; AECOM, 2012), and one each from Germany (Hübler et al., 2008) and Spain (Roldan et al., 2015). Middle and low income countries who are more vulnerable to extreme heat and have relatively low heat resilience capacity were not represented in this literature. All studies used historical health surveillance data to estimate the heat attributable healthcare costs. The study time-span ranged from 1 to 27 years. The type of data used includes hospitalizations, ED visits, ambulance call-outs, causes of death registry, and weather records. Four studies projected future heat attributable healthcare costs in a changing climate (Lin et al., 2012a; Toloo et al., 2015; AECOM, 2012; Knowlton et al., 2011).

Variations between studies were observed. In terms of study design, six were ecological studies, three were descriptive studies, and one was a case study. Moreover, differences in terms of health outcome measures, characteristics of study population, data source, types of heat metrics, statistical measures, and assumption of change in climate, population, and future healthcare cost were observed. However, all research used cost description method to estimate the economic impacts of extreme heat to the healthcare system.

3.1. Current heat-attributable healthcare costs

3.1.1. Costs of heat-attributable hospitalizations

The six studies from the USA calculated heat attributable economic costs of hospitalizations (Jagai et al., 2017; S. Lin et al., 2012; Merrill et al., 2008; Noe et al., 2012; Schmeltz et al., 2016; Knowlton et al., 2011). Among these studies, three were descriptive (Merrill et al., 2008; Noe et al., 2012; Schmeltz et al., 2016), two were ecological (Jagai et al., 2017; S. Lin et al., 2012), and one was a case study (Knowlton et al., 2011). Four studies analyzed hospital admission records associated with heat-related illnesses (Jagai et al., 2017; Merrill et al., 2008; Noe et al., 2012; Schmeltz et al., 2016). Knowlton et al. and Lin et al. specifically investigated heat attributable excess hospitalizations for all-cause and respiratory diseases, respectively (S. Lin et al., 2012; Knowlton et al., 2011). Daily mean apparent temperature (AT) (S. Lin et al., 2012), average monthly maximum temperature (Tmax) (Jagai et al., 2017), and heatwave (Knowlton et al., 2011) were used as temperature exposure metrics, while three studies (Merrill et al., 2008; Noe et al., 2012; Schmeltz et al., 2016) did not clearly indicate the use of meteorological temperature measurements. Great variations were observed on the scope/type of healthcare cost estimations. Two studies estimated excess cost (S. Lin et al., 2012; Knowlton et al., 2011), two studies calculated total/overall cost for the entire study period (Jagai et al., 2017; Noe et al., 2012), while others calculated costs per hospital stay (Merrill et al., 2008), or mean cost per hospitalizations (Schmeltz et al., 2016). Most of these studies stratified the result into population subgroups such as by age, gender (S. Lin et al., 2012; Merrill et al., 2008; Noe et al., 2012; Schmeltz et al., 2016), income (Lin et al., 2012a; Merrill et al., 2008; Schmeltz et al., 2016), race (Noe et al., 2012; Schmeltz et al., 2016), insurance conditions (Lin et al., 2012a; Noe et al., 2012; Schmeltz et al., 2016), and geographic region (Jagai et al., 2017; Merrill et al., 2008; Noe et al., 2012).

Lin et al. estimated the annual excess heat attributable hospital costs from respiratory disease in New York State. The study encompasses >95% of all respiratory related acute care admissions in the state. The average excess annual respiratory hospitalization cost between 1991 and 2004 was estimated to be $644,069, nearly $6500 per admission (Lin et al., 2012a). Schmeltz et al. studied the costs of hospitalizations due to heat-related illness (HRI) using a National Inpatient Sample (NIS) data from 2001 to 2010 and found a nationally adjusted mean cost of $5359 (95% CI: $5327–$5390) per hospitalization (Schmeltz et al., 2016). The overall healthcare cost due to HRI for the study period (10 years) was nearly $392.2 million.

Knowlton et al. studied healthcare costs due to major categories of climate-related events in the United States from 2000 to 2009 and the 2006 California heatwave was presented as a case study (Knowlton et al., 2011). The study used the number of excess hospitalizations attributed by the 2006 heatwave reported in their previous study (Knowlton et al., 2009) to calculate healthcare costs. They also used cost data from the Healthcare Cost and Utilization Project (HCUP). According to the findings, the overall economic cost of hospitalizations associated with the 2006 heatwave in 2008 US dollar value was nearly $28 million. The cost per admission was about $18,000. This cost is nearly 3 times higher than the result ($6200) reported by Merrill et al. using the 2005 NIS data (Merrill et al., 2008). A study which covers 97% of hospitals in Illinois, USA revealed that the total heat-stress illness hospitalization charge between 1987 and 2014 was 168 million, approximately $6 million per year during the 28 years of study period. The mean per person hospitalization charge was $20,500 (in 2014 US dollar value) (Jagai et al., 2017). Another US study by Noe et al. used fee-for-health service claims submitted to Medicare for hyperthermia-related visits. The study found an overall heat related healthcare cost of $36 million during 2004–2005 (Noe et al., 2012). Comparison of hyperthermia associated medical care costs of these two consecutive years demonstrated an increase by more than double, from $11 million in 2004 to $25 million in 2005.

An interdisciplinary study which combined knowledge from medical, meteorological, geographical, and economic field was conducted in Germany to estimate the national health damage costs of the rising temperature in the changing climate. Due to lack of suitable data on costs of heat related treatment and medication in practice, the study used federal state general hospitalization costs per case. The study presented a total annual cost of $98 million between 1971 and 2000 (Hübler et al., 2008).

Demographic factors associated with heat attributable hospitalizations depend on population sensitivity and adaptive capacity (Cui et al., 2005; Bi et al., 2011). The majority of published literature suggested a lower risk of heat exposure among females (Jagai et al., 2017; Merrill et al., 2008; Noe et al., 2012; Schmeltz et al., 2016) while the cost of treatment for heat-related illnesses was found to be higher for females than males (S. Lin et al., 2012; Schmeltz et al., 2016). For example, Schmeltz et al. in the USA reported that the average cost per HRI hospitalization for females from 2001 to 2010 was $5922 (95% CI: $5858–$5985), higher than males by nearly $800 (Schmeltz et al., 2016). In New York, Lin et al. found that females contributed 86% of the overall excess costs of heat associated respiratory hospitalizations per year during 1991–2004 (S. Lin et al., 2012). At an individual patient level, costs of heat attributable respiratory hospitalization were greater in females by approximately $500 than males. This disparity may be due to the biological susceptibility of females such as pregnancy conditions.

In terms of age, people over 75 years were estimated to cost an extra $1586 (95% CI: $1466–$1707) per heat-related hospitalization in the USA, compared to younger age groups (Schmeltz et al., 2016). Results of Lin's study in New York State showed that 16–64 and ≥ 75 age groups had similar excess costs per year (about $240,000) for heat associated

Table 1
Summary of studies on health and economic costs of high temperature associated with ambulance call-out, ED visits, and hospitalizations; ordered according to the county of origin.

Author and year	Country	Study period	Heat indices	Data type and sources	Study design	Statistical methods	Health outcome measures	Scope/types of cost	Main findings	Projection for future costs
Jagai et al. (2017)	USA, Illinois	1987–2014	Average monthly maximum temperature (Tmax)	Monthly hospitalization rate from all public and private hospitals using the Illinois Department of Public Health (IDPH) Hospital Discharge Database	Ecological study	Multi-level linear regression models	Heat-stress illness	Total and mean per person hospital charge	A 1 °C increase in monthly Tmax was associated with 0.34 and 0.02 increase in rural and urban heat-stress illness (HSI) hospitalization per 100,000 population respectively. The total hospital charge for HSI cases was $167.7 million with a mean charge of $ 20,500 per person per year.	No
Knowlton et al. (2011)	USA, California	2000–2009	Heatwave (extreme heat >2 consecutive days)	Total hospitalizations, ED, and outpatient visits obtained from literature and public health agencies and cost data from healthcare cost and utilization project (HCUP)	Case study	Extrapolation of cases, derivation of costs, and climate model	All-cause morbidity	Excess cost	An estimated total healthcare visits of 169,881 were observed. The cost of excess hospitalization, ED visit, and outpatient visit in 2006 heatwave was estimated to be $28,435,000, $14,110,000, and $136,380,000 respectively.	No
S. Lin et al. (2012)	USA, New York State	1991–2004	Daily mean apparent temperature (AT)	Daily respiratory hospitalizations of public and private hospitals from the New York State Department of Health State-wide Planning and Research Cooperative System database	Ecological study	Two-stage Bayesian model	Respirator disease	Excess cost	An estimate of 100 excess annual hospital admissions during the baseline year with associated costs of $0.64 million. Projected heat attributable hospitalization costs for the period 2046–2065 and 2080–2099 ranges from $5.5 to $7.5 million and from $26 to $76 million respectively.	2046–2065 2080–2099
Merrill et al. (2008)	USA, Nationwide	2005	Not used	Hyperthermia admission from HCUP (2005) Nationwide Inpatient Sample (NIS) database	Descriptive study	Descriptive statistics	Heat-related illness	Per heat-related hospital stay	A total of about 6200 heat-related hospitalizations with a cost of $6200 per hospitalization were observed in 2005. The poor and people in rural areas were the most vulnerable groups.	No
Noe et al. (2012)	USA, Nationwide	2004–2005	Not used	All hyperthermia inpatient and outpatient data obtained from nationwide Centers for Medicare and Medicaid Services	Descriptive study	Crude incidence rate and Mantel-Haenszel rate ratios (IRR)	heat-related illness	Total cost	The number of hyperthermia healthcare visits were 10,007 with a mortality rate of 0.06 per 100,000. The median hospital stay was 2 days and the overall total estimated cost was $36 million.	No
Schmeltz et al. (2016)	USA, Nationwide	2001–2010	Not used	Total heat-related illness (HRI) Hospitalization data from NIS database	Descriptive study	ANOVA and log-gamma model	Heat-related illnesses	Mean cost per hospitalization	Higher mean cost of hospitalization associated to hot ambient temperature was evident among ethnic minorities: Asian/Pacific Islanders $1208 ($793–$1624) followed by black $319 ($197–$440). Females and older peoples share the highest cost accounting $5922 ($5858–$5985) and $1586 ($1466–$1707) respectively.	No
AECOM (2012)	Australia, Melbourne	2012	Heatwave (3 days of ≥35 °C) and single hot day/maximum temperature/	Ambulance transport with/without spot treatment, and ED presentation (>64 years) data from the literature	Ecological study	Interpolation of health and cost data, climate model	Heat-related illnesses	Total cost	The total undiscounted heat driven (heatwave and single hot day temperature) costs of ambulance service for 2012, 2030 and 2050 were $32,800, $99,300, and $154,400 respectively. ED visit cost for the age group 64+ were $5800, $21,000 and $29,800 for each respective year. The overall discounted cost for ambulance service and ED during 2012–2051 was $2,604,500 and $489,200 respectively.	2030 2050
Toloo et al. (2015)	Australia, Brisbane	2000–2012	Daily Tmax	Daily ED visit was provided by Queensland Health Department	Ecological study	Generalized linear regression with Poisson link	All-cause morbidity	Excess cost	During the baseline year, older people (≥65) have a higher risk of 1.09 (95% CI: 1.06–1.13) of ED visit on hot days (≥35 °C). The number of excess visit was projected to be 98–336 (2030) and 229–2300 (2060) for younger groups and 42–127 (2030) and 145–1188 (2060) for older people. Based on 2012–13 prices, heat attributable extra cost was anticipated to be between $59,232–$195,693 in 2030 and $162,587-1,496,221 in 2060.	2030 2060
Hübler et al. (2008)	Germany, Nationwide	1971–2000	Heatwave	Data from all States meteorology, geography, medical and economic fields	Ecological study	Exponential extrapolation and Regional Climate Model	All-cause morbidity	Total annual cost	The baseline (1971–2000) hospitalization cost was $98 million. The total projected annual cost of hospitalization for the period 2071 to 2100 was estimated to be about $592 million.	2071–2100
Roldan et al. (2015)	Spain, Zaragoza	2002–2006	Daily Tmax	Daily in-hospital mortality data obtained from Public Health Directorate	Ecological study	Autoregressive integrated moving average model of a time series	All-cause mortality	Overall and total annual cost	Risk of mortality increased by 1.28 (95%CI: 1.08–1.57) above a threshold temperature of 38 °C. A total of 107 (95%CI: 42–173) deaths and an associated cost of $509, 978 (95% CI: $200,178–$824,544) was observed.	No

respiratory hospitalizations, however the number of excess heat attributable respiratory hospitalizations per year in the 16–64 age group was about 1.5 times (40 vs 27) higher than ≥75 age group. On the contrary, the study reported that higher temperature reduced the number of respiratory hospitalizations and costs in the 0–15 age group (S. Lin et al., 2012).

Taking the White population as a reference group, Schmeltz et al. found that the mean cost difference per hospitalization was $1208 higher (95% CI: $793–$1624) among Asian/Pacific Islanders; followed by Black, $319 (95% CI: $197–$440); and Hispanics, $243 (95% CI: $98–$387) (Schmeltz et al., 2016). The study also analyzed the economic burden associated with HRI hospitalizations among populations of lower income quartiles. The result indicated that the mean cost per hospitalizations for black and Hispanic populations were $432 (95% CI: $245, $620) and $262 (95% CI: $71, $453) higher than white, respectively. Similarly, Merrill et al. in the USA reported higher heat caused hospitalization rate and longer hospital stay among low-income populations compared to groups with higher income. Heat associated hospitalizations were >2 times higher among the poorest than the wealthiest communities across the USA (Merrill et al., 2008).

Length of hospital stay is another indicator used to reflect heat healthcare burden and disease severity. Jagai et al. found that the median and mean length of hospitalization from heat-stress illness in Illinois, USA, from 1987 to 2014 were 3.7 and 2.0 days respectively (Jagai et al., 2017). Similarly, Noe et al. in the USA used Medicare and Medicaid service data and reported an increase of hospital stay from 2 days in 2004 to 3 days in 2005 possibly due to warmer temperatures in 2005 throughout the USA (Noe et al., 2012). This finding is in accordance with the result reported by Merrill which used data from HCUP, USA, confirming 3.2 days of average hospital stay (Merrill et al., 2008). In New York, the total excess days of hospitalization due to heat attributable respiratory diseases were estimated to be 616 days per year (approximately 6 days per admission) during 1991–2004. Moreover, nearly 84% of the heat attributable excess annual hospital stays were from females (533 days) and 36% from those aged ≥75 years (238 days) (S. Lin et al., 2012).

3.1.2. Costs of heat-attributable ED presentations

Three of the reviewed studies calculated heat attributable ED service costs (Toloo et al., 2015; AECOM, 2012; Knowlton et al., 2011). The two studies in Australia (Toloo et al., 2015; AECOM, 2012) aimed to examine the health and economic impacts of extreme temperature using age as demographic risk factor (Toloo et al., 2015; AECOM, 2012). Populations aged 65 and above were included in both studies using maximum temperature, or heatwave, as the heat metric (AECOM, 2012). While Toloo et al. and Knowlton et al. studied all-cause heat attributable morbidity and the associated excess healthcare costs (Toloo et al., 2015; Knowlton et al., 2011), the study in Melbourne specifically focused on heat-related illnesses and its overall/total healthcare costs (AECOM, 2012).

The study by Toloo et al. examined costs of ED visits over the warm seasons of 2000–2012 in Brisbane, Australia, using all-cause excess ED visits. A total of 22 hot days with maximum temperature (Tmax) ≥35 °C occurred and resulted in 135 excess ED visits over this period. The pricing approach "Urgency Disposition Groups (UDG)" was used to estimate the cost of heat associated ED visits. The cost was determined using the National Efficient Price (NEP) of 2012–13 set at $3624 multiplied by price weight (PW) of each triage category (from Most urgent = 1 to Least urgent = 5) and departure status (admitted, discharged) (Toloo et al., 2015). The overall extra ED cost for the base year (2012−13) was reported to be $61,625.The extra economic burden to the ED from all-cause morbidity associated with heat for 0–64 and 65^{+} age groups accounted a cost of $46,320 and $15,409 respectively. The study in Melbourne, Australia, estimated costs of ED visit for people aged 65^{+} in relation to heat (heatwave and single hot day) to be $5800 in 2012 (AECOM, 2012). In the study by Knowlton et al., for a 2006 heatwave in California, using health outcome estimations from literature and cost data from HCUP, a total cost of $150.5 million was reported due to all-cause excess ED and outpatient visits (Knowlton et al., 2011).

3.1.3. Costs of heat-attributable ambulance call-outs

We identified only one study, from grey literature, that has examined heat and ambulance call-out costs. The study was conducted in Melbourne, Australia, and considered high temperature (single hot day) and heatwave exposure on ambulance services costs (AECOM, 2012). The authors divided ambulance services into two categories: (1) ambulance attendance requiring transport to hospital assuming that all heat-related cases were taken to ED than direct admission to the inpatient department, and (2) ambulance attendance requiring on the spot treatment only. In 2012, the total costs of heat (heatwave and single hot day) driven ambulance dispatches requiring both road transportation and spot treatment was reported to be $32,800. Ambulance road service to patients of heat driven illnesses (heatwave and single hot day) contributed to a substantial proportion of costs compared to spot treatment ($31,000 vs $1800), higher by 17-fold.

3.1.4. Costs due to heat-related deaths

The only available study estimating the healthcare costs of extreme heat on mortality was an ecological study by Roldan et al. in Zaragoza, Spain (Roldan et al., 2015). The study investigated extreme heat attributable additional mortality associated healthcare costs above the temperature threshold of 38 °C. The study used a cost of $4773 per death, derived by averaging costs associated with heat attributable in-hospital deaths, obtained from the Ministry of Health. The total mean extra cost during the entire five years (2002 to 2006) was estimated to be $509,978 (95% CI: $200,178–$824,544) with highest annual mean costs of $271,362 (95% CI: $104,736–$447,509) in 2003 (Roldan et al., 2015).

3.2. Climate change and heat-attributable healthcare burden

Four studies projected future heat attributable healthcare costs by extrapolating the baseline heat-health relationships and cost burden to future climate change (S. Lin et al., 2012; Toloo et al., 2015; AECOM, 2012; Hübler et al., 2008) and population scenarios (Toloo et al., 2015; AECOM, 2012; Hübler et al., 2008). All of these studies suggested a significant increase in heat attributable healthcare burden without efficient interventions.

3.2.1. Hospital admissions

Lin et al. in New York projected the mean summer apparent temperature (AT) for two future periods: 2046–2065 and 2080–2099 (S. Lin et al., 2012). The highest future AT was projected from high greenhouse gas emission scenario (A2) followed by mid emission (A1B) and low emission (B1) (IPCC, 2013). By the middle of the 21st century, heat attributable respiratory hospital admissions were projected to range from 190 to 260 per year in New York under lower to higher emission scenarios, which would be 1.9–2.6 times more than the baseline years (1991–2004) of hospitalizations. The resultant heat attributable additional healthcare costs were estimated to be between $5.5 million and $7.5 million per year. Compared to the reference period, the cost per admission increased by 4–5-fold ($6400 vs $29,000). The annual total days of heat attributable respiratory hospitalizations were projected to be 1202–1630 days in the coming 50 years and this would be raised to 3744 days in 100 years, increased by 6-fold compared to the base years. Using a high emissions scenario, the number and cost of annual excess heat associated respiratory admissions would increase by 2.6 and 11 times by midcentury and 6 and 118 times by the end of the century respectively. The costs were adjusted to healthcare service price inflation and standardized to 2004 USD using an annual discount rate of 3%. However, these projections assumed that the relationship between extreme temperature and health outcomes, demographic profiles, and

temperature-health thresholds at the baseline level remain constant (S. Lin et al., 2012).

Additional hot days were estimated for Germany and its surrounding using regional climate model (REMO) which has a better spatial and temporal resolution than the global climate models. The prediction used the Intergovernmental Panel on Climate Change (IPCC) A1B scenario for 2071–2100. The research indicated that the national average healthcare costs of treating heat-attributed diseases in the hospital would be $592 million per year, a 600% increase compared to estimated costs for the baseline years (Hübler et al., 2008). Nearly 54% ($265 million) of future annual healthcare cost change would be due to climate change while 46% ($228 million) would be contributed by the change of demographic profile. The projected number of hot days was 2–5 times more than the reference period (1971–2000) with an associated increase of projected costs by 6-fold. The heat associated hospitalization costs would represent 0.9% of the all-cause hospitalization costs in Germany and 0.3% of the country's health care expenses (Hübler et al., 2008).

3.2.2. ED presentations

Based on the ED data from 11 public hospitals in Brisbane, Australia, the projections by Toloo et al. suggested a considerable increase of excess ED visits on hot days under the highest population growth and climate change scenarios (Toloo et al., 2015). The number of excess annual heat attributable ED visits for the age groups of 0–64 years and >64 years in 2030 was projected to be between 98–336 and 42–127, respectively, compared to 118 and 31 in the baseline years. The corresponding estimated excess annual costs ranged from $38,444–$138,700 for the 0–64 age group and $20,352–$63,319 for the >64 age group. Without interventions, in 2060 the number of heat attributable excess annual ED visits was projected to reach 229–2300 for the 0–64 age group and 145–1188 for the >64 age group, resulting in a cost of between $90,456–$904,568 and $72,365–$592,492, respectively. The study suggested that future heat driven ED costs for the >64 age group would grow twice as much as the 0–64 age group, which would add up to an extra cost of around $58,796–$195,989 in 2030 and $162,068–$1,496,306 in 2060 (Toloo et al., 2015).

A study in Melbourne used predictions of heatwaves and single hot day temperatures for 2030 and 2050 to estimate ED presentation costs for the elderly (64^{+} years) (AECOM, 2012). High (A1FI) and low (A1B) greenhouse gas emission scenarios (IPCC, 2013) were used which suggested a 5.5 °C and 2 °C increase of temperature by the end of the 21st century compared to the 1990 level, respectively. The study used historical heat-health relationships and considered population change and forms of urban development into account. The results indicated that overall heat attributable ED visit costs would increase by 3 times in 2030 and by 5 times in 2050, compared to the base year (2012) (undiscounted cost). The overall heat (heatwave and single hot day) attributable ED cost for the population of 65^{+} years would be approximately $416,000 from 2012 to 2051 at present value discounted by 3% (AECOM, 2012). However, the study indicated that single hot day temperature would contribute the highest ($292,000) ED cost compared to heatwave ($123,900).

3.2.3. Ambulance call-outs

Only one study from Melbourne projected the increased cost of heat attributable ambulance services due to climate change. The study investigated the cost of heat extremes from 2012 to 2051 considering socio-economic and climate change. It showed that the overall heat (heatwave and single hot day) attributable cost of ambulance services would be $99,300 in 2030 and $154,400 in 2050 (undiscounted cost), showing an increasing heat attributable cost by nearly 3 fold and 5 fold compared to the 2012 costs, respectively (AECOM, 2012). Looking at heatwave alone, the cost of ambulance services, including road transport and spot treatment, would be $70,300 in 2030, three-fold higher than the baseline year, and $111,600 in 2050, five times higher than the baseline cost (undiscounted cost). The overall discounted (at 3% rate) cost of all heat driven ambulance call-outs from 2012 to 2051 was estimated to be over $2.1 million (AECOM, 2012).

4. Discussion

It is likely that future heat exposure will be more severe and increasing in geographic range due to the changing climate (Pachauri et al., 2014). While many studies have examined the likely health impacts, to date there have been only 10 studies that have explicitly addressed the healthcare costs of heat extremes. These studies use different exposure and outcome measures, study population and period, and assessment which largely prevents a direct comparison of estimates. However, all the studies indicate that health costs of heat exposure constitute a substantial economic burden, which will increase markedly in the future. The estimates for current annual costs range from $46,000 to 39 million for hospitalizations, from $5800 to $150 million for ED visits, and approximately $33,000 for ambulance call-outs, depending on the location, health outcomes, and population examined.

Most studies estimated the costs of heat attributable healthcare service utilization based on the underlying heat-health relationships. Therefore, any factors affecting the estimation of heat-health relationships also influence cost estimations. In the following sections, our discussion is focused on factors that might influence cost estimations, directly or indirectly. Sections under 4.1 describe factors which may affect the heat-healthcare cost relationship, including heat metrics used, health outcome measurements, and estimation of baseline heat attributable healthcare costs. In Section 4.2, future climate change and heat-healthcare burdens are presented.

4.1. Heat-healthcare cost relationship

4.1.1. Selection of heat exposure indicators

In the measurement of heat-related healthcare cost impacts, different heat indices have been used, including maximum daily temperatures (Toloo et al., 2015; Roldan et al., 2015), mean AT (S. Lin et al., 2012), average monthly maximum temperature (Jagai et al., 2017), and heatwaves (AECOM, 2012; Knowlton et al., 2011). The selection of temperature indicators, heat thresholds, and different heatwave definitions may influence the estimation of health risks and heat-attributable healthcare costs. There is no consensus in the literature about which heat indicator is the best in predicting heat-induced health outcomes and, accordingly, healthcare costs. Some heat-health outcome studies have reported that different heat indicators had similar predictive ability (Barnett et al., 2010), with no single temperature measure superior to others (Barnett et al., 2010; Yu et al., 2011). Apparent temperature, a combination of air temperature, wind speed and relative humidity, has been reported to be a better temperature measure in some locations (Y.K. Lin et al., 2012; Morabito et al., 2014) and this metric was used by Lin et al. (S. Lin et al., 2012) for the estimation of heat attributable respiratory hospitalization costs in New York.

Due to the nonlinearity of the heat-health outcome association (Song et al., 2017), identification of threshold temperatures is important to quantify heat driven adverse health impacts and associated healthcare costs. Three studies have taken nonlinearity into account when calculating excess heat driven health burden and associated costs (S. Lin et al., 2012; Toloo et al., 2015; Roldan et al., 2015). It is worth noting that the estimation of the burden on health services and costs could vary substantially depending on the estimate of threshold temperatures. However, some studies estimated the overall heat attributable health and economic burden (Merrill et al., 2008; Noe et al., 2012; Schmeltz et al., 2016) other than quantifying the magnitude of excess heat attributable burden. On the other hand, use of aggregated data, for example a study by Jagai et al., can significantly influence the statistical predictive capacity of the model which may affect cost estimation (Jagai et al., 2017).

Several studies estimated health outcomes and costs in relation to heatwave exposure, for a single heatwave event (Knowlton et al., 2011), or for multiple events in a given study period (AECOM, 2012; Hübler et al., 2008). Costs for individual heatwave events are likely to show considerable variation because the health impacts will vary according to the length and severity of the heatwave.

4.1.2. Measurement of heat health outcomes

Appropriate measurement of heat-health outcomes is fundamental to understand the cost burden of heat extremes. However, exposure to heat can cause varieties of illnesses, symptoms, and exacerbate a range of pre-existing medical conditions. Heat-related morbidity and mortality from respiratory, cardiovascular, heat-related illnesses, and renal diseases have been found to escalate during hot seasons (Liao et al., 2010; Jagai et al., 2017; S. Lin et al., 2012; Merrill et al., 2008; Noe et al., 2012; Schmeltz et al., 2016). The broad range of health effects introduces some uncertainty in the diagnosis of heat-related illness, which can (Luber and McGeehin, 2008; Ye et al., 2012) lead to erroneous heat-cost associations.

In the verification of heat-associated illnesses, triangulation of clinical diagnosis results and local weather data are recommended to reach a sound conclusion. In some instances, it is hard to establish the etiologic agents of morbidity and mortality events and oftentimes missed to be classified as heat-related (Luber and McGeehin, 2008). On the other hand, during heatwave periods, it is more likely that patients visiting healthcare facilities to be diagnosed as heat-induced illness, leading to potential over-reporting of heat attributable illnesses. Few studies used medical records solely to verify heat-related morbidity and mortality (Merrill et al., 2008; Noe et al., 2012; Schmeltz et al., 2016). However, these records might be incomplete (Krieger, 1992) and lack accuracy leading to a biased conclusion. Inaccurate estimation of heat-related health impact will likely lead to imprecise cost estimation.

The magnitude of effect estimation of heat exposure on population health and healthcare cost could depend on the type and number of confounding factors considered. The association between extreme heat and health may be confounded by some environmental and socioeconomic factors which may potentially affect cost estimation (Zuo et al., 2015; Ye et al., 2012) directly or indirectly. Studies by Toloo et al. and Lin et al. controlled confounding factors including long-term trend, seasonality, the day of the week, and ozone (O_3) in the examination of heat and health relationship and thereafter to quantify excess heat attributable medical costs (Lin et al., 2012a; Toloo et al., 2015). In addition, Toloo adjusted for the use of air conditioner, particulate matter with an aerodynamic diameter of <10 μm, and nitrogen dioxide (Toloo et al., 2015).

4.1.3. Estimation of heat-healthcare costs

The current literature describes the direct economic cost of heat driven healthcare resource utilization and has not considered the broader societal costs (Gardiner et al., 2017). This review has considered the evidence in relation to hospital (ED visits and admissions) and ambulance costs. Costs are also incurred in primary healthcare settings, for example, community nursing and general practitioners (Huang et al., 2013; Ebi et al., 2004), however, these costs are more difficult to capture at a state or national level and there has been no published research evidence in this area.

As indicated in the conceptual framework (Wee and Banister, 2016) (Fig. 2), the direct cost to the healthcare system can be categorized into fixed costs which includes salary, equipment, and building costs. This fixed cost cannot be saved over a short term whether patients of heat induced health outcome use the service or not. However, the second type of cost to the healthcare system known as variable cost, can vary based on the amount and type of service used (Roberts et al., 1999). These are costs to medications, disposable supplies, and test reagents. Such cost can significantly increase if the demand for health service increased due to ambient heat extremes. However, it is unclear whether the range of this cost refers to government or to customers/patients as there might be different arrangements of healthcare cost payment including direct purchase model (out-of-pocket) and the third party payer model with co-payment system (including out-of-pocket, private insurance, or government).

All these studies examined the cost associated with heat driven illnesses using a cost description method. Even if studies clearly quantified the burden of extreme temperature to the healthcare system in

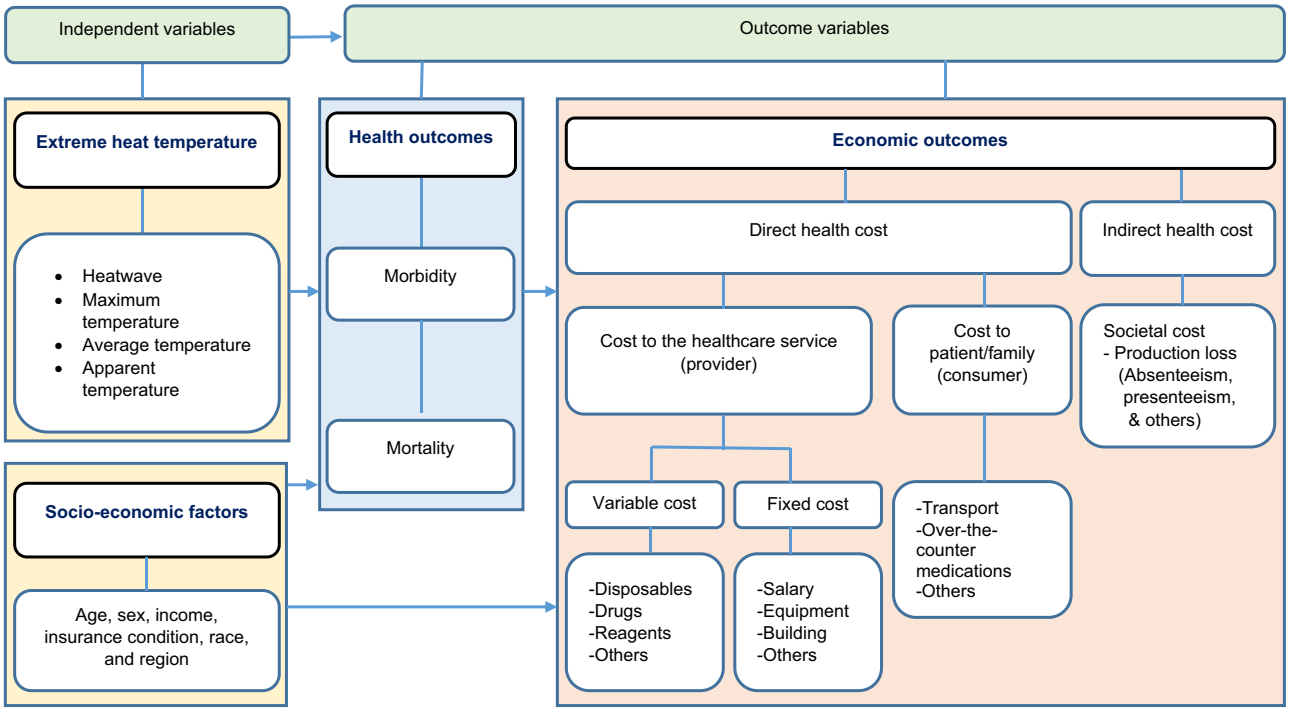

Fig. 2. Representation of factors affecting health and healthcare costs of extreme heat.

monetary terms, the results can be more useful if they are compared with costs of other possible options in addressing health problems associated with extreme temperature including disease prevention and health promotion, heat warning system, climate mitigation, and adaptation activities. Since health economic studies mainly aimed to provide information to decision and policy makers for efficient use of available resources for maximizing health benefits (Dang et al., 2016), allocation of resources based on disease burden studies to the healthcare system alone could not necessarily lead to efficient resource utilization. Therefore, relative costs and benefits of investing healthcare resources on either preventive or curative health interventions, including opportunity cost, needs to be thoroughly evaluated.

Health impact cost studies particularly focusing on the costs of disease treatment in monetary units are very limited in part because of the challenge of getting a comprehensive cost data both from private and public healthcare facilities and lack of consensus on health cost valuation methods (Knowlton et al., 2011). Hence, a couple of studies used statistical extrapolation methods, a judgmental forecasting beyond the range of original observation (Holt, 2004), to estimate the economic damages associated with exposure to heat extremes (Hübler et al., 2008; Knowlton et al., 2011). Because of the absence of actual cost data on heat-related treatment and medication in Germany, statistical estimation of hospitalization cost was made using hospital emergency admission as a proxy indicator, which may underestimate the real costs. Jagai et al. used hospital billed charge to estimate costs of disease treatment (Jagai et al., 2017). However, hospital billed charge does not necessarily reflect the actual cost to the hospital of providing patient care. Compared to cost, hospital billed charge could be inflated and it might not accurately measure the costs of medical service utilization (Jagai et al., 2017). The amount of money reimbursed, and the real cost of service delivery reasonably vary. Some studies calculated adjusted health service utilization cost by using cost-to-charge ratio (CCR) (Lin et al., 2012a; Merrill et al., 2008; Schmeltz et al., 2016) which can provide a better picture of service production cost. Studies suggested that CCR was more recommended to be used in the estimation of costs per diagnosis-related groups than individual patient level (Shwartz et al., 1995).

The research by Toloo et al. in Brisbane, Australia calculated ED cost using the NEP and PW methods (Toloo et al., 2015). This method is primarily developed for funding arrangement in the Australian healthcare system (Bell et al., 2014). Apart from the PW difference, the same value of NEP ($3624) was used to calculate the cost of ED visit for heat attributed cases visiting different triage scales which varies by urgency (from most urgent to least urgent) and admission (admitted or discharged) status. The difference in the complexity of care provided within the same urgency groups could not be adequately captured by either NEP or PW. The cost calculation could be more aggregated and might not be able to accurately measure cost differences between disease severity levels and ultimately leads to underestimation of ED costs. Moreover, it could be hard to capture whether temperature variation caused cost differences or not.

For most studies conducted in the USA, the NIS, which was developed as part of the HCUP was used as the sole source of data (Merrill et al., 2008; Noe et al., 2012; Schmeltz et al., 2016). The database encompasses a large sample of longitudinal hospitalization discharges of the USA population (nearly 8 million). However, apart from sample size, the NIS dataset is limited to the population covered by Medicare, which may vary from the non-Medicare population in terms of heat vulnerability and thereby affect cost estimation (Kinney et al., 2008).

Most mortality studies used the VSL to estimate the health cost in monetary terms (Huang et al., 2013; Ebi et al., 2004). Since the focus of this review is on actual healthcare resource utilization to treat diseases from heat exposure, the mortality study by Roldan and colleagues was the only study identified for healthcare mortality costs. However, this estimate of additional heat induced hospital spending could not rule out the cost variation between deaths from heat and non-heat causes other than frequency differences. The cost estimation would have been more meaningful if it includes medical expenditures to save the life of a person.

4.2. Climate change and heat-healthcare burden

Understanding future climate and its economic impact on our healthcare system can be used to effectively plan preventive actions. Studies used the current/past temperature-health relationship to calculate future health outcomes and estimate the cost of health service utilization (S. Lin et al., 2012; Toloo et al., 2015; AECOM, 2012; Hübler et al., 2008). However, looking at future climate effects embraces key uncertainties in the observation of main drivers at regional and global climate projections. Forecasting future climate resilience is challenging due to the lack of data and uncertainties arising from climate models. Few studies used a global climate model to project regional climate variables that have course spatial scale resolutions compared to regional climate models (S. Lin et al., 2012; Toloo et al., 2015; AECOM, 2012) (Hübler et al., 2008). Nevertheless, the uncertainty of projection increases with the increase of the projection period. Factors such as the interaction of environmental variables and urbanization could affect projections (Toloo et al., 2015). Overall, it is difficult for studies to account for the complex interplay of many variables, including future adaptation, possible changes in medical care, and costs of health services.

For economic assessments, the comparisons of costs and benefits at different point of time require cost adjustment to enable comparison of future and current costs and benefits (Li et al., 2018). In the economic estimation, a considerable uncertainty exists from the methodological framework which is still debatable by health economists and uncertainty surround the data (Briggs and Gray, 1999). For projection of future heat attributable healthcare cost, some studies used an annual discounting rate of 3% (S. Lin et al., 2012; AECOM, 2012). These studies also adjusted for inflation, an increase in the price of healthcare services and goods at the future time, while projection studies by Toloo et al. (Toloo et al., 2015) and Hübler et al. (Hübler et al., 2008) assumed that the cost of future healthcare price remains constant with the baseline years which is unlikely.

Economic studies helps to improve allocative efficiency of healthcare resources which taken into account the production and distribution of health outcomes among the community (Aday et al., 1999). The increasing future temperature will disadvantage certain groups of the populations. Projection studies suggest that the aging populations would be experiencing greater health and economic burdens associated with ever increasing temperature (S. Lin et al., 2012; Toloo et al., 2015). Higher prevalence of chronic diseases, impaired thermoregulatory functions, and use of certain medications could aggravate the effects of heat load on older population. Disease severities could be potentially higher among older population than younger group. A relatively lower ED cost for elderly group (64^{+}) in Melbourne could be due to the fact that the spot treatment provided by the ambulance service making it the patients endpoint and others with severe heat driven illnesses were admitted directly to the inpatient department (AECOM, 2012). Even though the prediction study by Hübler et al. in Germany did neither account future change in sectoral pattern of the economy nor adaptation to climate change, it suggested that heat-induced cost of hospitalization would increase significantly (Hübler et al., 2008). Unless preventive strategies are designed, heat driven health service demand will increase during hot seasons which will obviously result in higher healthcare costs (AECOM, 2012).

5. Further research needs

Only a small number of studies addressed economic costs of heat extremes, and methodological limitations in creating more advanced economic evaluations were observed. Appraisal of the available research protocol and developing standard and robust methodological

foundation could be a research area. Even though 10 studies quantified heat-attributable healthcare cost based on heat-health association, there is a need to explore the causal relationship between temperature exposure and healthcare costs. Apart from descriptive statistics, advanced correlational analysis of healthcare cost could be applied. Healthcare cost estimation should be explicitly defined from societal, government or patients/families perspectives and cost adjustment is needed.

Selection and use of appropriate temperature thresholds can help to determine the magnitude of health and economic impact associated with extreme ambient heat exposure. This can better inform relevant stakeholders to plan, allocate, and mobilize resources efficiently. Moreover, economic evaluation or cost effectiveness studies between costs of disease treatment and other alternatives of managing health impacts of extreme temperature for example: potential savings from heat-health interventions are highly recommended to advice public health intervention strategies.

Use of excess heat factor (EHF), a more universal and new definition of heatwave (Zuo et al., 2015; Langlois et al., 2013; Nairn and Fawcett, 2014), can help to calculate temperature attributable excess costs and enables comparison of research results regardless of climatic variations. The relevance of healthcare cost spending in predicting disease severity can be other benefits researchers need to proof.

It is likely that future heat is more severe and increasing in geographic range due to the changing climate. However, the available studies are unevenly distributed, and some parts of the world particularly those most vulnerable regions with the least resilience were underrepresented and further empirical evidence is required to see the global pictures of economic damage to the healthcare system.

Getting underlying detailed costs of health service utilization remains as a challenge. Collection and storage of routine healthcare cost data can strengthen the research endeavour and increase the availability and precision of economic costing studies in the health sector. A comprehensive healthcare cost analysis from both private and public healthcare systems of all levels (from primary to tertiary health care) is required.

6. Conclusion

This literature review indicates that the health costs of high-temperature exposure constitute a substantial economic burden on healthcare systems in the USA, Australia, and Europe. Although the evidence is still developing, studies have suggested that the subgroups incurring greater heat attributable costs include females, the elderly (≥64 years), low-income families, and some ethnic minorities. It is apparent that the future healthcare costs of extreme heat are likely to increase dramatically, globally and most particularly in more heat prone areas without effective heat adaptation measures. Monitoring of health outcomes and healthcare spending in relation to heat exposure may strengthen the research endeavours in the field. It is time for government agencies and policy makers to give more attention to the likely increasing heat attributable healthcare burden in a warming climate.

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Conflict of interest

The authors declare that they have no actual or potential competing financial interests exist.

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